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ULTRASONIC DETERMINATION OF BODY COMPOSITION

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FOREWORD

This research was conducted under contract number F33615-67-C-1414, by Cornell University, Ithaca, New York 14850, for the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. Dr. J. R. Stouffer, the principal investigator, directed the contract effort. Mr. W. R. C. White assisted in carrying out experimental procedures, compilation of data and preparation of the technical report. The work was done in support of project 7183, "Psychological Research on Human Performance," Task 718301, "Fundamental Parameters of Human Performance." The research was started in February 1967 and completed in March 1968.

Distribution of this report is provided in the interest of information exchange.

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Aerospace Medical Research Laboratory

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ABSTRACT

The object of this study was to determine the feasibility of using ultrasonic techniques to determine the volume of fat, muscle, and bone tissue of the living body. Ultrasonic equipment, including a mechanical scanning and recording device was used to produce cross-sectional maps of a live anesthetized hog, three fresh hams, and three human subjects (endomorphic, mesomorphic, and ectomorphic). Thirteen 360° cross-sectional scans on the live hog demonstrated the feasibility of using the technique on live animals. Cross sections of the three hams demonstrated the accuracy of estimating the areas and volumes of the three tissue components from ultrasonic scans. The ultrasonic mapping of the human subjects demonstrated that the technique could be used on all parts of the human body and, in addition, provided an indication of the range of values of individuals of diverse body types.

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SECTION I

INTRODUCTION

The measurement of body composition has become important in biological research and clinical medicine. Many techniques and procedures have been developed to measure various components of total body composition.

Anthropometric measurements are relatively easy to obtain but do not provide the accuracy demanded of science today. Skinfold thickness calipers have been widely used as indicated in recent reports by Booth et al, 1966, and Sloan, 1967. Body density determinations (Young,1960) have also been used fairly extensively although the method requires a permanent installation rather than having the portability attributes of other techniques.

Ultrasound has been used (Temple, 1956; Hazel and Kline, 1958; East et al, 1959; Price, 1960; Stouffer, 1961) to measure fat thickness on live cattle and hogs and then comparisons were made with actual measurements on their carcass. These results have encouraged others (Whittingham, 1962; Booth et al, 1966; Bullen,et al, 1966; Sloan, 1967) to use ultrasonic equipment on humans to measure fat thickness in several locations and relate these to other, indirect measures of body fat.

The object of this study was to determine the feasibility of using current ultrasonic techniques to determine the volume of fat, muscle and bone tissue of the living human body.

SECTION II

MATERIALS AND METHODS

SUBJECTS AND MATERIALS

Step 1. Ultrasonic Scanning of Animals.

A series of cross sectional maps of the bodies of two live lambs and one hog were made, using the ultrasonic scanning equipment, in prelininary studies to determine the species that would be more appropriate for comparison with subsequent serial transverse ultrasound scanning in live human subjects. The decision was made not to use lambs because of their light weight, approximately 40 kg, and because of the dense coat of wool which would cause difficulty in the penetration of sound waves.

The animal used in the experiment was an 80 kg Yorkshire barrow. It was anesthetized and then scanned 360° at each of 13 positions,

using the surface contact method with ultrasonic scanning equipment. The area scanned included the head; the neck; three positions in the thorax region; three positions in the lumbar region; three positions on the rear leg; the right foreleg; and the right upper foreleg. It was not possible to make a complete 360° scan on the position of upper foreleg and one position on the rear leg due to the conformation of the animal. Line drawings were made from the photographs of the original ultrasonic scans in such a fashion as to delineate clearly and accurately the areas of skin and fat, muscle, bone, and other major anatomical structures that could be identified. A comparison of line drawings with original ultrasonic scans are shown in figures 10, 11, and 12 on pages 38, 39, and 40.

The accuracy of these maps to depict the areas of the various tissue was determined by killing the hog, freezing it at -25C and making cross section cuts on a meat and bone saw at the same positions at which the ultrasonic scans were made. Comparison of the directly measured areas of tissue and the same areas measured from the ultrasonic maps from selected positions are on table I, page 14. The location of the 13 sites for ultrasonic scans are illustrated in figure 1. Photographs of ultrasonic scans and cross sections at selected sites are shown in figure 2.
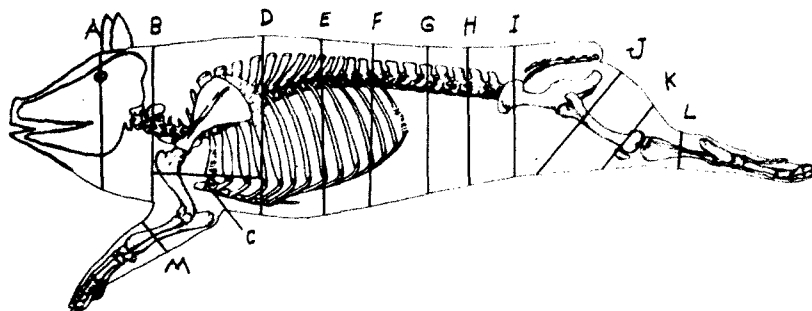
Figure 1. SITES OF ULTRASONIC SCANS ON HOG

Step 2. Determination of Accuracy.

The accuracy of the ultrasonic scanning technique to depict accurately cross sectional areas of a segment of a living animal was determined by scanning the ham of three hogs comparable in cross sectional area to the human thigh. These animal segments were

SECTION E
Tenth Rib
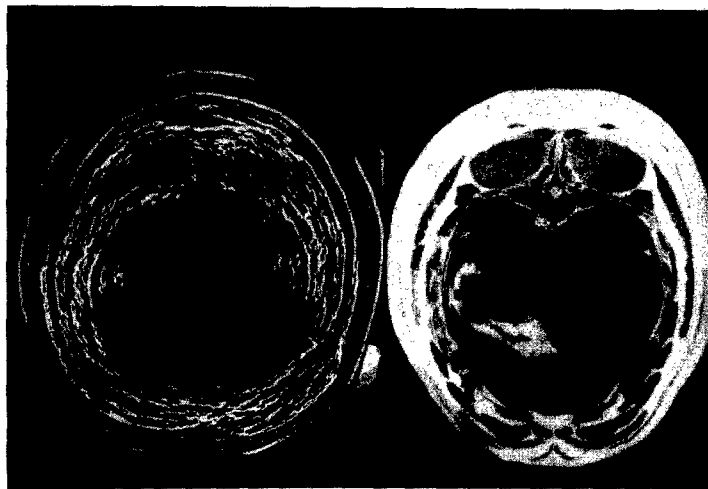
SECTION F
Thirteenth Rib
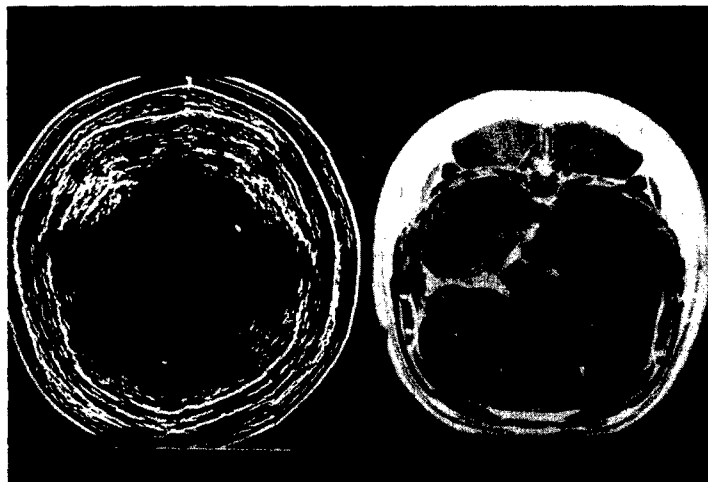
SECTION G
Fourth Lumbar
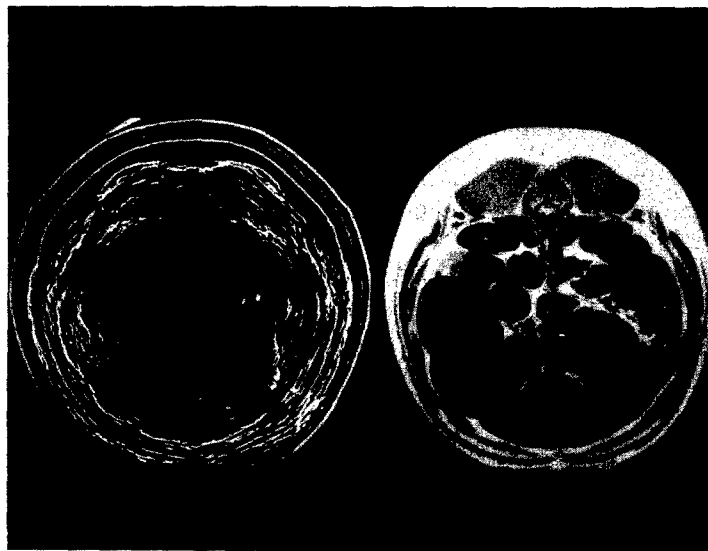
Figure 2, ULTRASONIC SCANS AND CROSS SECTIONS AT
SELECTED SITES ON HOG

scanned and mapped at regular intervals perpendicular to and over the entire length of the femur. This area was selected because it represented a range in the proportion of tissues. The ham used in Trial 1 was scanned at 2 centimeter intervals, while the ham used in Trial 2 was scanned at 1.5 centimeter intervals. Maps from the ultrasonic scans of these two trials were assembled and traced by comparing them with the actual cross sections obtained after the ham was cut. This was necessary due to the lack of an available accurate cross sectional anatomy presentation of such areas. In Trial 3 a ham was scanned at 1 cm intervals and the interpretation of the ultrasonic scans of this specimen consisted only of those cross sections obtained in Trials 1 and 2 or published cross sectional maps of similar segments.

In all three trials the accuracy of estimating the volumes of fat, muscle, and bone tissue were assessed by comparing the volumes of these tissues estimated by analysis of ultrasonic drawings with the volumes of the tissues as revealed by gross dissection of the actual cross section. A summary of the data from this phase can be found in table II, page 16. Photographs of selected ultrasonic scans and comparable ham cross sections are illustrated in Figure 3.

Step 3. Ultrasonic Scanning of Human Subjects.

Three living human subjects, chosen to be representative of three body types (Subject A, predominantly endomorphic; Subject B, predominantly mesomorphic; and Subject C, predominantly ectomorphic), were selected for ultrasonic scanning. The subjects were male, exhibited no evidence of debilitating pathology or trauma and were aged 24, 29, and 30. The technique developed to produce cross sectional maps of animal segments was used to produce a similar series of transverse cross sectional maps of selected body parts of the three human subjects. Ultrasonic scans were made on subject B, the mesomorphic type, at 1 cm intervals, starting at the forehead and proceeding to the distal end of the tibia. Only the right arm and leg were scanned at these intervals. Ultrasonic scans were made throughout the length of the right thigh of each of the remaining two subjects. From these scans, cross sectional maps showing the comparative distribution of fat, muscle, and bone in one thigh of each of the three subjects were produced. In addition, ultrasonic scans from six selected trunk areas of subjects A and C were obtained to relate these observations with comparable values on subject B.

METHODS FOR DETERMINING COMPOSITION

Ultrasound Method

The technique used in the evaluation of cross sections of animal and human bodies involves moving a transducer on a fixed guide corresponding to the contour of the part of the body being examined.
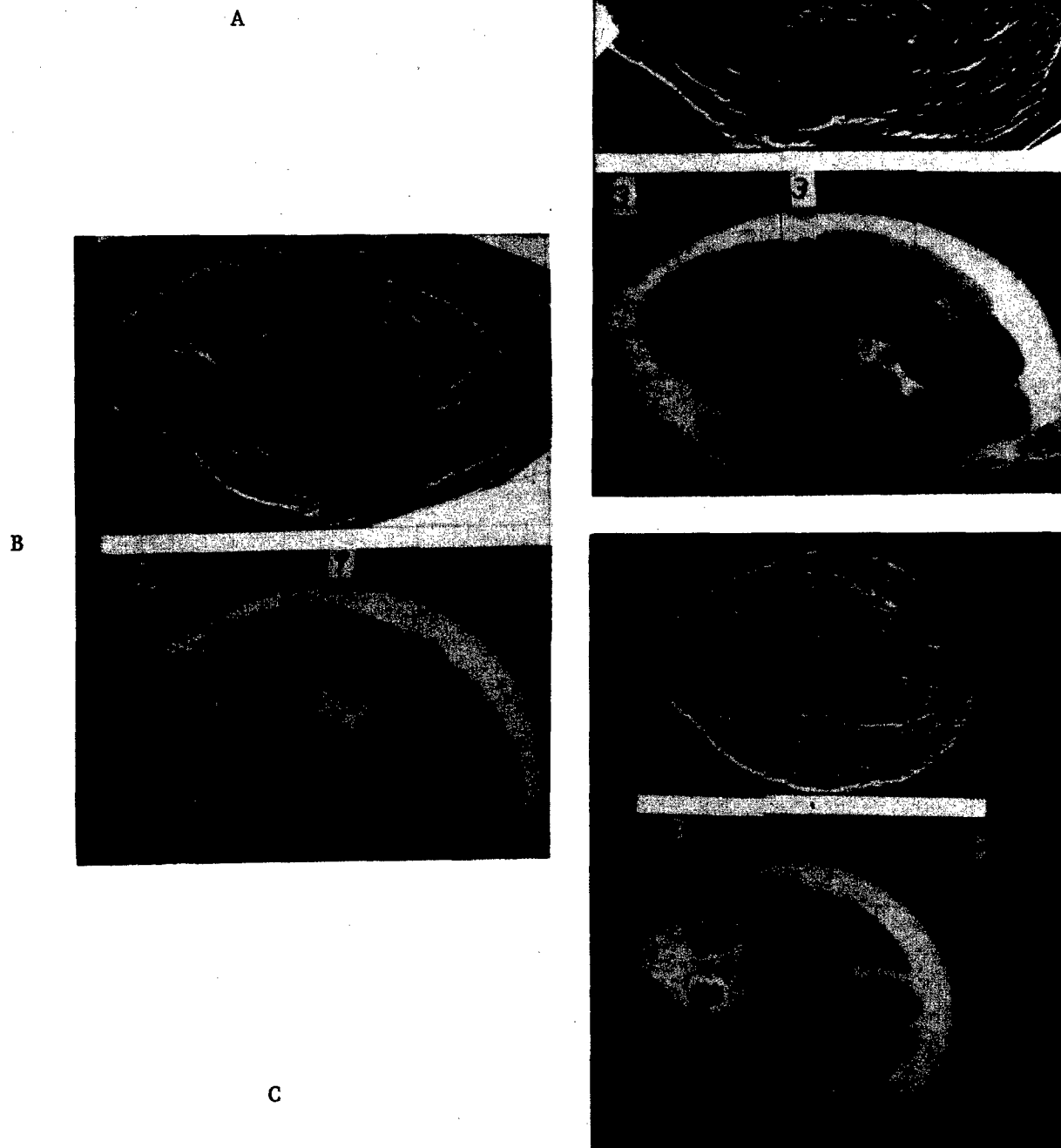
Figure 3. ULTRASONIC SCANS AND HAM CROSS SECTIONS
AT SELECTED INTERVALS

Several years of study with animals of various species have demonstrated that this can be accomplished using only a few fixed guides of different shapes and dimensions. A Polaroid camera back on a movable plate is moved at a rate and angle proportionate to the transducer on the fixed guide through a mechanical connection. The rapid print processing feature of this system permits the evaluation of a completed scan before proceeding on to the next position. It is also convenient to match photographs by virtue of known relative position or by identifying similar tissue characteristics on adjacent prints.

The surface contact scanning method was used on the live hog in Step 1 and was tried on the ham on Trial 1 of Step 2. However it became apparent that a more accurate and repeatable method could be carried out in an easier and faster manner by using an immersion technique. This technique was used for all subsequent scanning.

Step 1. Ultrasonic Scanning of Animals

A surface contact scanning method was used on the live hog for recording the 13 cross sectional area scans. A combination of two different curved guides was used in various combinations throughout the carcass to ensure optimum contact. However this was extremely difficult in a few selected areas which involved sharp curves of the surface of the live animal. Interpretation of the cross sectional ultrasonic maps in the thorax and lumbar regions was very good, while those on the extremities were incomplete in some instances.

Step 2. Determination of Accuracy

On the first ham in Trial 1, two different techniques of immersion scanning were compared in evaluating the ham. For both methods the ham was suspended in water and the transducer made contact with a polyethylene liner containing the water bath. In the first technique the transducer was held at a constant angle as it moved along in a linear manner on the outside of the polyethylene. This method proved satisfactory only when the reflecting surfaces within the ham were at an optimum angle in relation to the direction of the beam path. The overall performance of this technique was marginal and therefore was not used again. The technique that proved to be more accurate and the forerunner for the live human evaluation was a method for moving the transducer on a fixed guide that corresponded for the most part to the curvature of the segment under investigation. A limited amount of surface contact scanning was tried on the hams comparable to that done on the live hogs. However, the difficulty in maintaining perfect contact without disturbing the shape of the tissues being examined convinced the operators that this technique was not feasible for continued use. Therefore, all subsequent investigations with ultrasound were by a modified immersion technique. Scanning intervals

at 2 cm were used in Trial 1, because the method of holding the transducer guide and attempts to position it at more closely spaced intervals could not be done with acceptable accuracy. This technique was improved for Trial 2 of Step 2 and we were able to make the comparable scans at 1.5 cm intervals. Further refinements were made for Trial 3, which permitted accurate positioning of scans at 1 cm intervals throughout the length of the ham.

The accuracy of estimating the volumes of skin, fat, muscle, and bone tissues by analyses of ultrasonic drawings were assessed by comparing them with the volumes of the tissue as revealed by gross dissection of the actual cross sections.

The hams were placed in a freezer at -25 C immediately after scanning. After the hams were frozen, the end portions which were not scanned were removed on a power meat and bone saw and discarded. The center section was weighed and cut into sections corresponding to the scanning interval for each ham. Photographs of these sections were made at half scale for comparison with the ultrasonic scans which were also at half scale.

The ham sections were then dissected into skin, fat, muscle and bone and weighed while in a semi-frozen condition to minimize shrinkage and drip loss. The volume of each tissue component was then determined by water displacement.

The resolution of the ultrasonic records was not great enough to identify the thickness of skin at all times. However, we did not attempt to outline the skin on the hog in Step 1 nor the human subjects in Step 3.

Step 3. Ultrasonic Scanning of Human Subjects

The head, neck, trunk, and right upper leg of subject B were scanned at 1-cm intervals while he was lying in a shallow bath of 35C saline solution (approximately 7.5% salt). By providing a medium with the same acoustical characteristics as the tissues of the subject, acoustical distortion was prevented. The equipment for this method is shown in figure 4.

Two sequential 20-cm scans were made while the subject was lying supine and then prone in order to scan the full breadth of the body. Approximately 2-3 hours were required to do the complete scanning of an individual's back. An individual scan was required for each centimeter interval of his sides, neck, and head. A nose plug and breathing tube were used by the subject as the front of his face and neck were scanned. A continuous flow of paraffin oil from a pressure can was supplied to the face of the transducer as it moved along on the underside of the
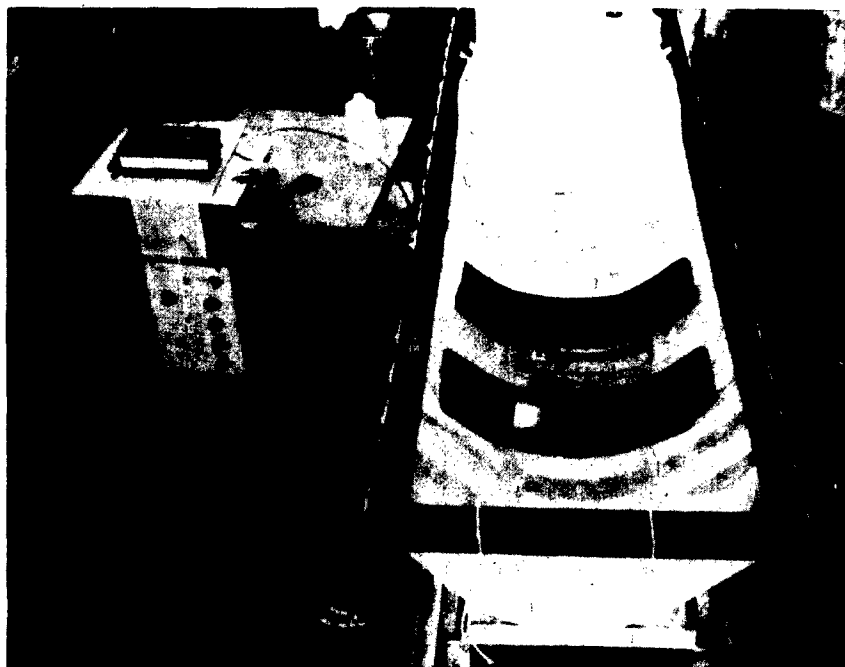
A. END VIEW
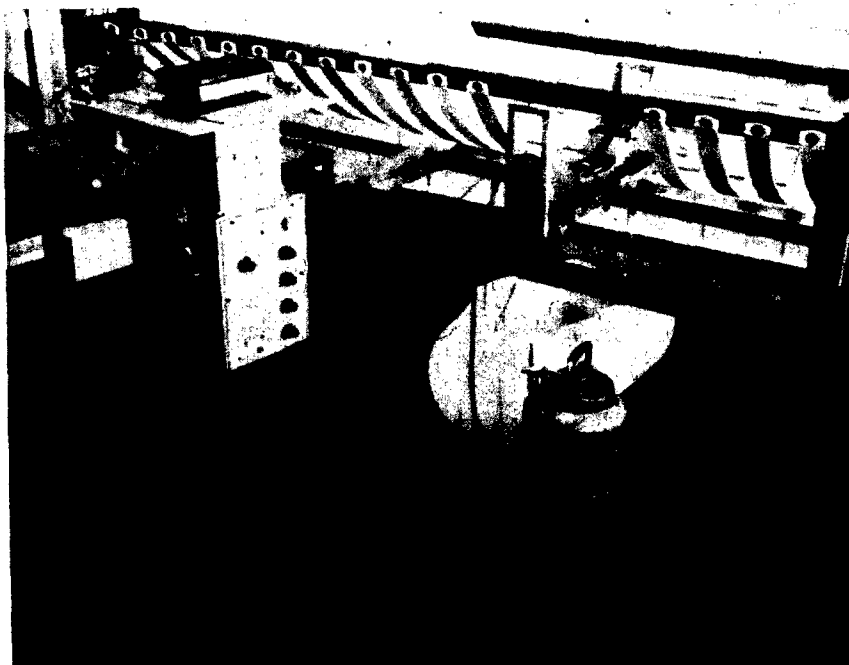
B. SIDE VIEW

FIGURE 4. ULTRASONIC EQUIPMENT

polyethylene liner which contained the saline solution. The bath was suspended from a frame 60 cm wide by 160 cm long and 78 cm from the floor. Five-cm wide canvas belts attached to the sides of the frame at 10 cm intervals supported the liner and water bath.

Pieces of hard rubber 2 cm thick and 44 cm wide by 10, 15, 30 or 40 cm lengths were used to support the subject, except immediately over the transducer guide. Successive serial scanning could be carried out with only minor delays that involved releasing canvas belts as the transducer guide replaced them temporarily. The various length hard rubber supports also could be moved with a minimum of delay and disturbance. This equipment is illustrated in figure 4, A. The shoulder area was scanned with the arms fully extended to assess the body composition as accurately as possible. The entire right upper leg and trunk of subjects A and C were similarly scanned for comparison. In this study only six selected sections of the trunk of subjects A and C were evaluated for comparison with subject B. These sections are shown in figures 8 and 9 on pages 19 and 20.

A technique similar in principle was used to make ultrasonic cross sectional scans of the upper arm, lower arm and lower leg on the right side of subject B. However, instead of providing a shallow tank for the subject to lie in, a cylindrical tube of thin polyethylene material approximately 22 cm in diameter was used to suspend an appendage in a vertical position. This would permit the subject to lie on his side while the arm was scanned and to sit conveniently on a flat surface while the lower leg was scanned. Two transducer guides were fixed so that it was possible to scan the outside of the upper arm, for example, and immediately scan the inside of the upper arm and be positive that these two scans were made at exactly the same level. This provided an opportunity for the two sectional scans to be properly assembled and accurately interpreted by use of maps for tracing of areas.

An outline of the subjects bodies was made while they were lying supine on a flat surface. This outline was used to make sure that the appropriate number of cross sections were made within a given region. The number of cross sections corresponded to the number of centimeters length within a given section of the body. It was also possible to make precise width measurements as well as length measurements for later use in assembling the photographs representing different sectors of the same section. Another technique that proved to be invaluable for later assembling the photographs to the correct scale was the use of solder wire to determine the precise curvature or profile of given cross sections of the body and appendages. It was possible to fit this solder wire to the shape of the section of the human body and then spread the wire sufficiently to move it from the body but still it would be pulled back in place and exact profile recorded on paper. These sections could be reduced to half scale and corresponded exactly to the proportions of the ultrasonic photographs.

All of the ultrasonic photograph records from a given section were fastened with tape to a sheet of paper so that the correct outline was established. Representative ultrasonic scans and comparable cross sections from an anatomy atlas are shown in figures 5 and 6.
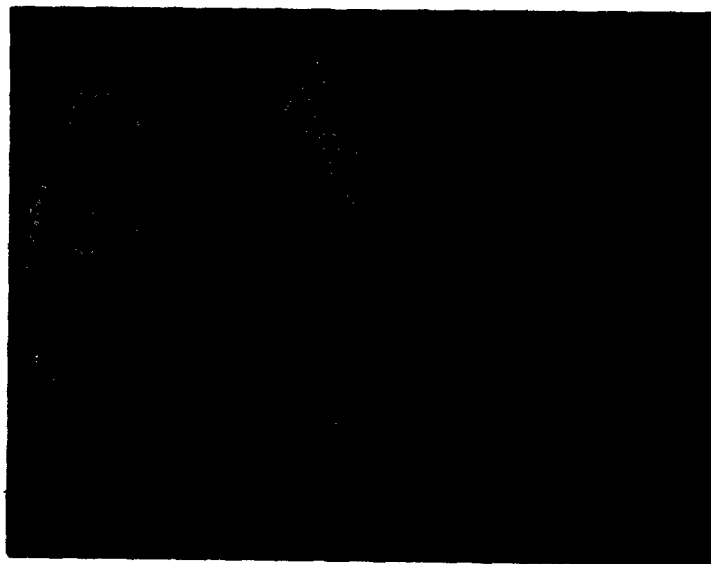
A. HEAD
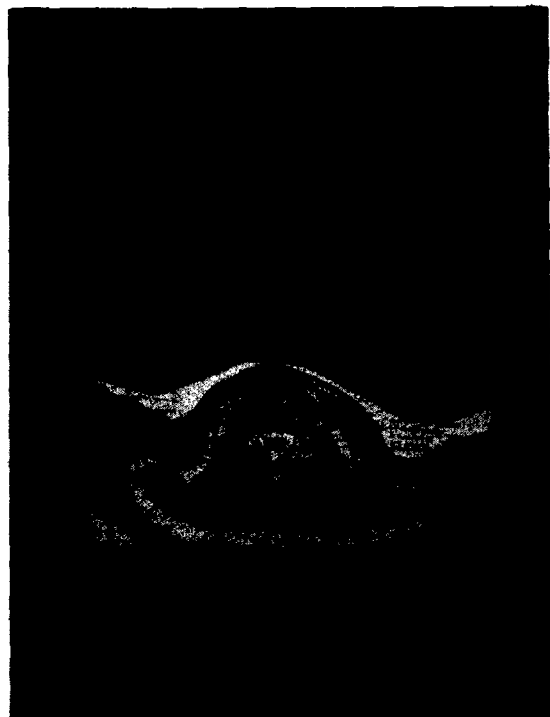
B. SHOULDER
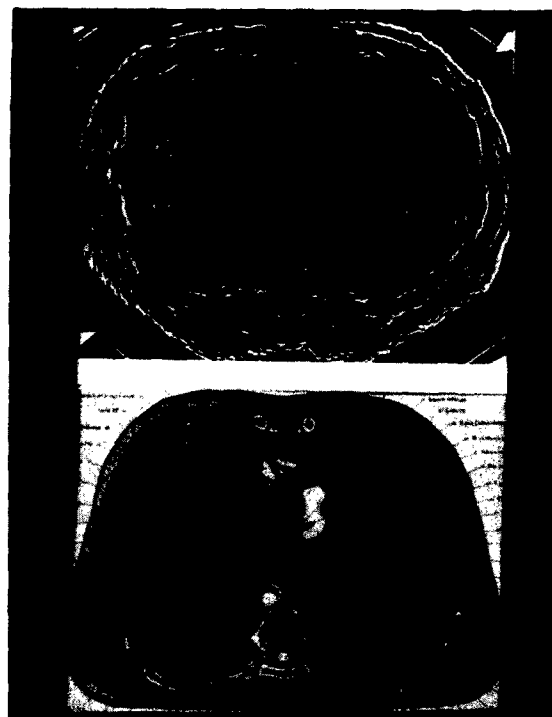
C. THORAX

Figure 5.   ULTRASONIC SCANS AND COMPARABLE CROSS SECTIONS
FROM ANATOMY ATLAS

I   UPPER BODY
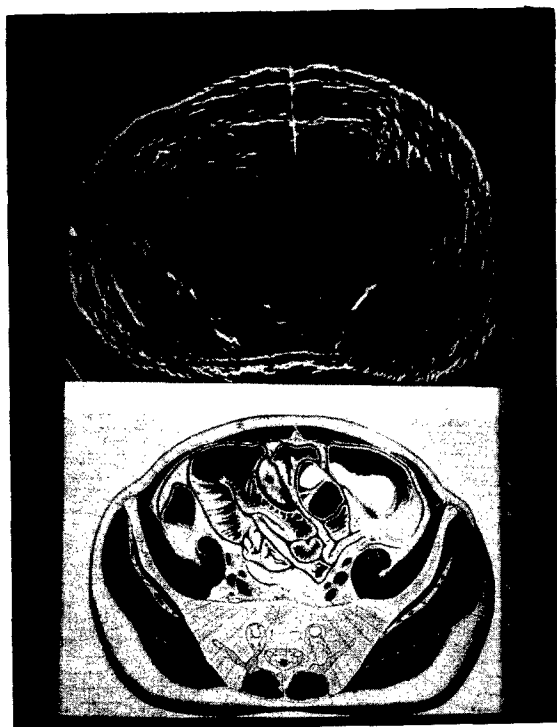
A. PELVIS
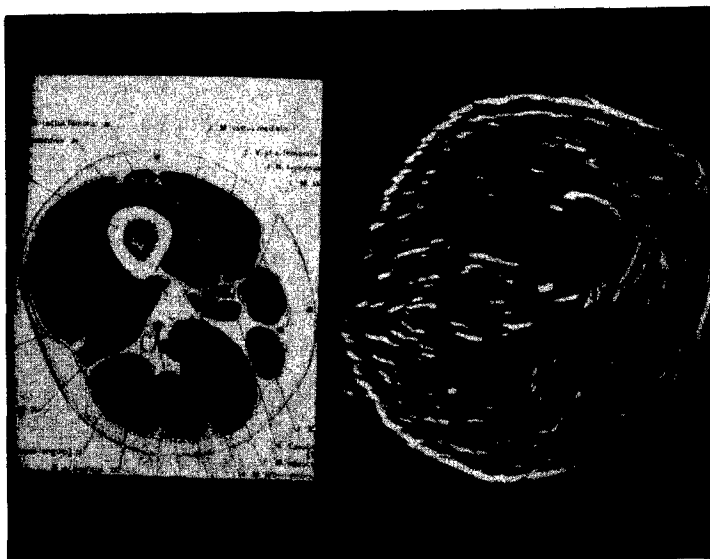
B. UPPER LEG
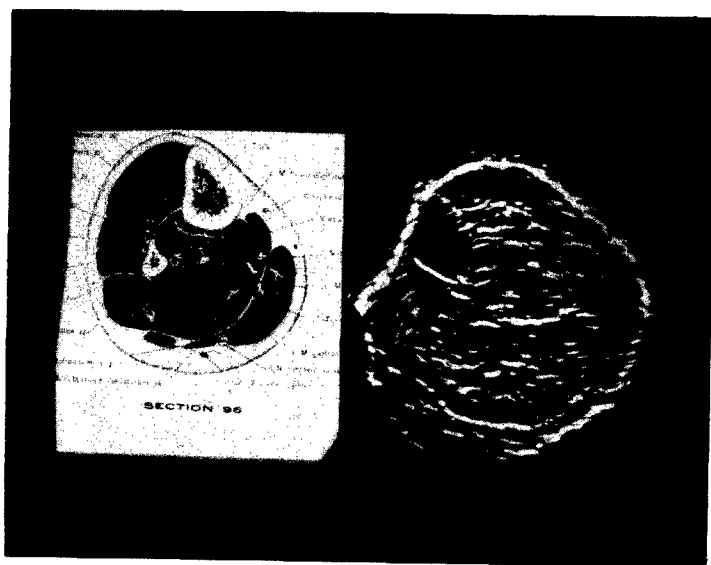
C. LOWER LEG

Figure 6.   ULTRASONIC SCANS AND COMPARABLE CROSS SECTIONS
FROM ANATOMY ATLAS

II   LOWER BODY

Comparable sections from an atlas (Eycleshymer and Schoemaker, 1911) were used as a reference to aid in the interpretation of the specific tissue areas as the line drawings (ultrasonic maps) were made on acetate paper. Figures 11 and 12 show comparisons of line drawings with original ultrasonic scans from selected body regions. Areas of each tissue mass within a cross section were measured with a compensating polar plantimeter and the data recorded.

Densitometric Method

The fat content of the body was also estimated by the densitometric technique as described in Young et al, 1960. A correction was made for the volume of residual air in the lungs at the moment of weighing by employing the open-circuit nitrogen dilution method. For the purposes of calculation of body fat from density, the Rathbun and Pace formula was used. The equipment for this method is shown in figure 7.

Figure 7. DENSITOMETRIC EQUIPMENT

The apparatus used consisted of a large cement tank filled with water at 37 C + 1. An aluminum chair suspended from a 20-kg scale (calibrated to 20 g) was attached to an electric hoist that raised or lowered the seated subject into the tank. By means of a snorkel connected with a series of tubes and valves, the subject could breath either room air or inspire oxygen from a spirometer and expire into a Tissot spirometer. The oxygen from the cylinder was saturated with water vapor before being fed into the spirometer. Subjects were weighed before breakfast (in a post absorptive state). They wore very brief swimming trunks.

For the initial stages of the hydrostatic weighing, the valve of the snorkel tube was turned to allow the subject to breath room air. The Tissot gasometer and connecting tubes were flushed six times with 6 liters of oxygen each time. The subject was seated in the weighing chair, and secured with the attached safety belt. Following a preliminary instruction period he was connected with the snorkel device by means of a rubber mouthpiece and his nostrils closed with a nose clip. Weighings were made at the end of an expiration when the subject was fully submerged in the water. When the underwater weights read to the nearest 100 g checked on three successive trials, the subject was considered "trained". On the final submersion, at the moment the weight was taken, the valve of the snorkel was turned by remote control to allow the inhalation of oxygen from the spirometer and the exhalation into the Tissot gasometer. The chair was then raised so that the subject's head was above the water level and he breathed oxygen for 7 minutes. Later the underwater weight of the empty chair was obtained by lowering it to exactly the same depth as reached when weighing the subject. After the gas in the gasometer had been thoroughly mixed, samples were withdrawn for nitrogen analysis in a Thomas-Van Slyke Manometric apparatus.

SECTION III

RESULTS

Step 1. Ultrasonic Scanning of Animals

The accuracy of estimating tissue areas by ultrasonic scans is shown on table I. The first part of the table shows a comparison of only those carcass components comprised of bone, muscle, and fat, while the lower half of the table compares the total body components including the amount of body cavity. Good agreement is noted for these particular sections as indicated by the tabulated data and also by the comparison of the ultrasonic scans with the cross sections illustrated in figure 1, page 2 and figure 2, page 3. Visual comparison with all other ultrasonic scans and actual photographs of cross sections of the hog at other sections were found to be satisfactory.

TABLE I

ACCURACY OF ESTIMATING TISSUE AREAS BY ULTRASONIC SCANS COMPARED
TO DIRECTLY MEASURED AREAS OF TISSUE ON SELECTED SECTIONS OF A
HOG AS SHOWN IN FIGURE 2 PAGE 2

Carcass Components

Section	Tissue	Ultrasonic		Direct	
		sq cm	%	sq cm	%
E	Bone	3.5	3.0	4.9	4.3
Tenth Rib	Muscle	40.2	34.0	38.4	33.9
	Fat	74.6	63.0	69.9	61.8
	Total	118.3	100.0	113.2	100.0
F	Bone	4.3	3.9	5.6	5.2
Thirteenth	Muscle	36.6	33.1	32.5	29.9
Rib	Fat	69.6	63.0	70.5	64.9
	Total	110.5	100.0	108.6	100.0
G	Bone	3.8	3.4	3.4	3.2
Fourth	Muscle	36.9	33.2	40.1	37.9
Lumbar	Fat	70.4	63.4	62.3	58.9
	Total	111.1	100.0	105.8	100.0

Total Body Components

Section	Tissue	Ultrasonic		Direct	
E	Bone	3.5	1.9	4.9	2.8
Tenth Rib	Muscle	40.2	21.6	38.4	21.7
	Fat	74.6	40.0	69.9	39.5
	Body Cavity	68.1	36.5	63.7	36.0
	Total	186.4	100.0	176.9	100.0
F	Bone	4.3	2.1	5.6	2.7
Thirteenth	Muscle	36.6	17.5	32.5	15.6
Rib	Fat	69.6	33.3	70.5	33.8
	Body Cavity	98.5	47.1	99.9	47.9
	Total	209.0	100.0	208.5	100.0
G	Bone	3.8	1.8	3.4	1.7
Fourth	Muscle	36.9	17.8	40.1	20.0
Lumbar	Fat	70.4	33.9	62.3	31.0
	Body Cavity	96.4	46.5	95.1	47.3
	Total	207.5	100.0	200.9	100.0

Step 2. Determination of Accuracy

The accuracy of estimating tissue volumes by ultrasonic sections of the ham comparable in size to the human thigh are shown in table II. Close agreement of the figures are illustrated on the data from this table as well as in the photographs in figure 3.

Density values of pork skin, bone, muscle, and fat are not available from the literature. Therefore, we can only estimate that the variation which we have observed in the proportion of weight and volume of the ham sections dissected is within the normal range. Visually the hams varied in the amount of external fat and the inter-muscular fat or marbling. The difference in marbling may account for the lower apparent density of muscle in Trial 3. The estimate of volume of muscle and fat by ultrasonic mapping as compared with dissection values was better in Trials 2 and 3 than Trial 1. This was probably due to the improved technique and a better knowledge of what to expect from the gross anatomy. This would be reflected in the accuracy of interpreting the ultrasonic scans.

In view of the limited information on density of animal tissues and the limited use of ultrasonic scanning of animal segments, a continuation and expansion of this phase of this study should be carried out. It would also be well to include evaluation studies on the thigh or rear leg of sheep as well as swine. In many ways the thigh of sheep are more like humans than are hogs.

Step 3. Ultrasonic Scanning of Human Subjects

Approximately 85 anthropometric dimensions were measured on each of the three subjects by the Air Force technical monitors. Selected values are included in table VIII, appendix. Values for the individual cross sections of subject B are recorded in the appendix, in tables IX-XV and are listed according to major body regions. Comparable detailed sectional analysis from ultrasonic maps for subjects A and C thigh are included in the appendix in tables XVI and XVII. Data for subject B appears in table III and is a summary of data from tables IX-XV. The data for tissue components representing the head do not include bone. It was not possible to show more than one side of the skull thereby negating the accuracy of any estimate for bone thickness alone. Therefore, a combined figure was put in representing percentage of bone and cranial cavity. In all sections where skeletal tissue components were evaluated they were defined as muscle, bone and skin, and fat. The skin and fat values for the lower leg and lower arm appear extremely high, but they also represented a large group of tendons located around the major joints. These were grouped with skin and fat because we did not have a separate category for any other anatomical structure.

Table III also illustrates the accuracy with which we are able to

TABLE II

ACCURACY OF ESTIMATING TISSUE VOLUMES BY ULTRASONIC SECTIONS COMPARED TO VOLUME BY PHYSICAL DISSECTION OF HAMS (SELECTED SCANS AND HAM SECTIONS ARE SHOWN IN FIGURE 3 PAGE 5

Trial 1.   Ham scanned at 2-cm intervals

Tissue	Dissection Weight g	Dissection Volume cc	Dissection Volume %	Ultrasonic Mapping Volume cc	Ultrasonic Mapping Volume %
Skin	200	222	4.48	274	5.08
Bone	377	317	6.40	275	5.10
Muscle	3482	3275	66.09	3852	71.44
Fat	1026	1141	23.03	991	18.38
Loss in weight during dissection	100				
Total	5185	4955	100.00	5392	100.00

Trial 2.   Ham scanned at 1.5-cm intervals

Tissue	Dissection Weight g	Dissection Volume cc	Dissection Volume %	Ultrasonic Mapping Volume cc	Ultrasonic Mapping Volume %
Skin	204	208	5.44	189	4.74
Bone	322	271	7.08	225	5.64
Muscle	2597	2442	63.84	2581	64.97
Fat	813	904	23.63	996	24.96
Loss in weight during dissection	41				
Total	3977	3825	99.99	3991	100.01

Trial 3.   Ham scanned at 1-cm intervals

Tissue	Dissection Weight g	Dissection Volume cc	Dissection Volume %	Ultrasonic Mapping Volume cc	Ultrasonic Mapping Volume %
Skin	295	268	4.14	334	5.16
Bone	509	324	5.00	332	5.13
Muscle	4345	4222	65.20	4381	67.68
Fat	1466	1661	25.65	1425	22.02
Loss in weight during dissection	0				
Total	6615	6475	99.99	6473	99.99

TABLE III

COMPILATION OF BODY COMPOSITION OF SUBJECT B FROM MAPS OF ULTRASONIC SCANS
(MEASURED IN 1-CM SECTIONS)

	Total	Fat		Bone		Muscle		Body Cavity	
	cc	cc	%	cc	%	cc	%	cc	%
Head	656.7	104.0	15.9			214.6	32.7	338.1	51.1
Neck	129.3	25.4	19.7	12.6	9.7	84.9	65.7	6.4	4.9
Upper Trunk	5443.2	857.9	15.8	405.4	7.5	2082.2	38.3	2097.7	38.5
Lower Trunk	5270.4	884.8	16.8	485.9	9.2	2558.8	48.6	1340.9	25.4
Upper Leg R.	1730.6	307.5	17.8	155.1	9.0	1268.0	73.3	-	-
Lower Leg R.	926.2	253.4	26.3	198.3	21.4	484.5	52.3	-	-
Upper Arm R.	496.3	69.9	14.1	46.1	9.3	380.3	76.6	-	-
Lower Arm R.	409.3	93.2	22.8	55.1	13.5	261.0	63.8	-	-
Total	15062.0	2586.1	17.2	1358.5	9.0	7334.3	48.7	3783.1	25.1
Left Arm and Leg	3562.4	714.0		454.6		2393.8		-	
Sub Total	18624.4	3300.1	17.7	1813.1	9.7	9728.1	52.2	3783.1	20.3

x 4   Since this value represents 1/2 scale ultrasonic maps,
it should be multiplied by a factor of 4.

74497.6

x1.0596   This mass should then be adjusted to his body density. (1.0596).
78937.6

Hands   873.0
Feet   1714.0
Top of Head 2027.2
            4614.2   Determined by water displacement
            x1.1   and external measurements. Assume
            5075.6   density is 1.1

5075.6   g
78937.6 g   Weight from ultrasonic estimates
84013.2 g   Total weight by addition of estimates
83200.0 g   Actual body weight
813.2   g   Over estimated

account for all of the components as represented by the body of subject B. The total summation of all tissue components that we evaluated by the ultrasonic technique amounted to 15062 grams of tissue components, which is one-half scale of the actual. By adding the left arm and leg and raising this total to the actual cross section area, we arrived at 74.5 kg. When corrected for body density (1.0596) the weight becomes 78.9 kg. The weight of hands, feet, and top of the head, which were not measured ultrasonically, were determined by water displacement and by calculation. All of the components added to 84.0 kg. This compares with the initial body weight of subject B of 83.2 kg. This would amount to approximately 0.8 kg. over estimate of weight, as noted by a summation of the total parts, and this amounts to 0.9% error on original weight.

Ultrasonic maps from six comparable sections of the three human subjects were compared to ascertain if there might be a short cut method for determining body composition on living humans. A comparison was made with maps that were made from photographs of a cadaver at comparable locations. All of these measurements from the maps were adjusted to proportions comparable to our ultrasonic maps based on linear measurements. The range of values for skin and fat from our three subjects was 9.1 and 20.4 percent. The value of 16.1% was estimated for subject B, the mesomorphic type. The percentage of skin and fat as determined from comparable sections from the photographs of the cadaver was 16.6%. It was also very interesting that the area of the six comparable sections from the cadaver maps fell within the range for our human subjects. Although we did not have sufficient resolution to measure fat thickness layers on our sections of human subjects it is of interest to estimate actual fat thickness corrected for the amount of skin. Information in the literature (Wilmer, 1940) indicated that we should expect approximately 6% of the body weight to be made up of skin. The data in table IV indicates that we were recording larger percentages of skeletal tissues and a smaller proportion of body cavity than compared to the atlas or the actual cadaver. This could be a real difference between living subjects and cadavers or the atlas, although I suspect this would indicate that our ultrasonic unit was not precisely calibrated. Our scanning method involves showing where the muscle, fat and bones are located and assuming that the balance of the area was body cavity.

A comparison of the tissue components from the thigh or upper leg of all three subjects is made in table V. The variations in

-18-
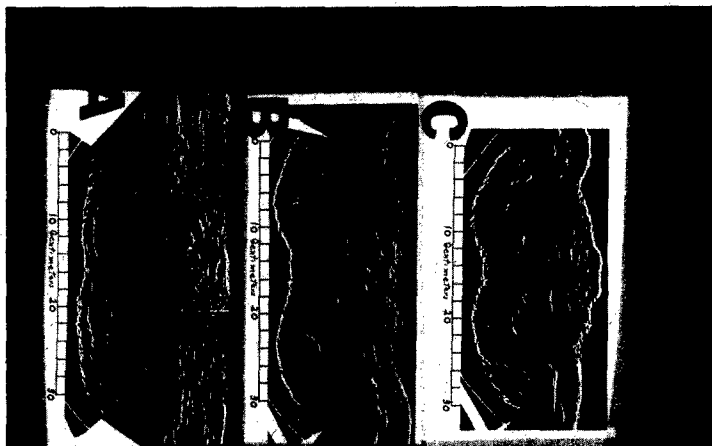
SECTION I

SECTION 2
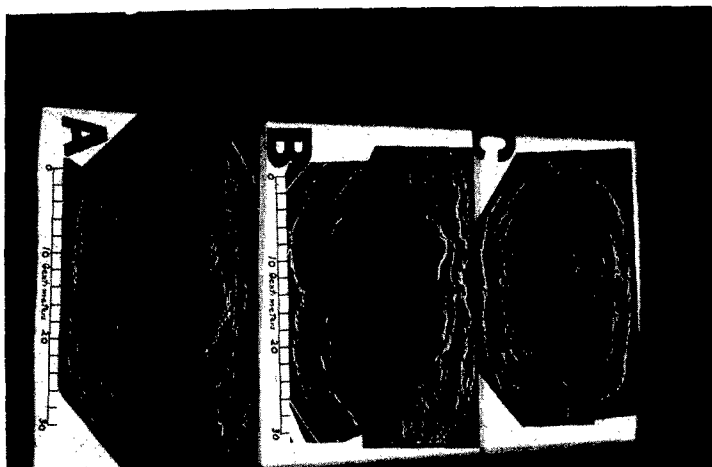
SECTION 3
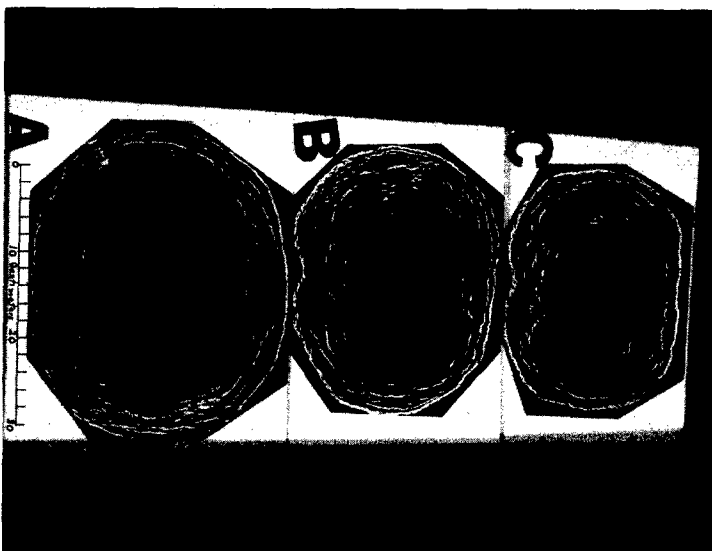
Figure 8. ULTRASONIC SCANS AT 6 SELECTED POSITIONS
ON 3 SUBJECTS

I UPPER TRUNK

-19-
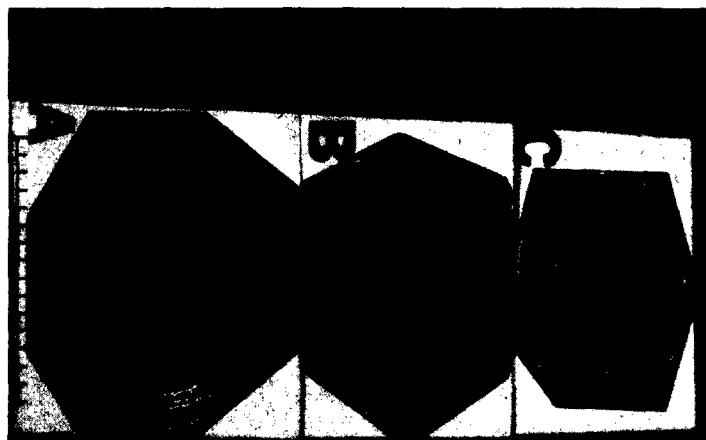
SECTION 4

SECTION 5
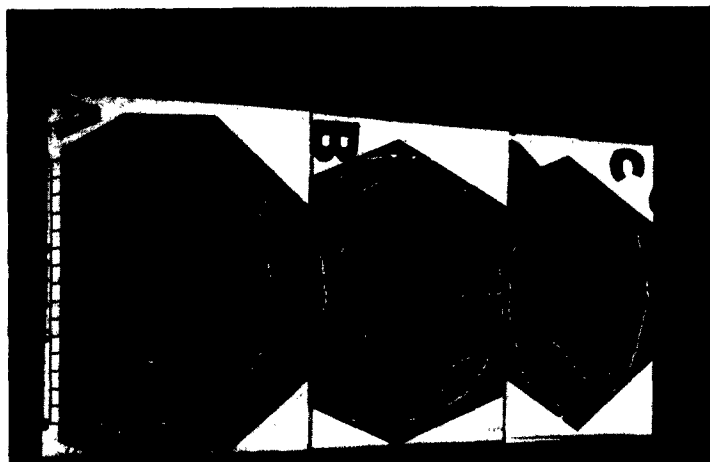
SECTION 6
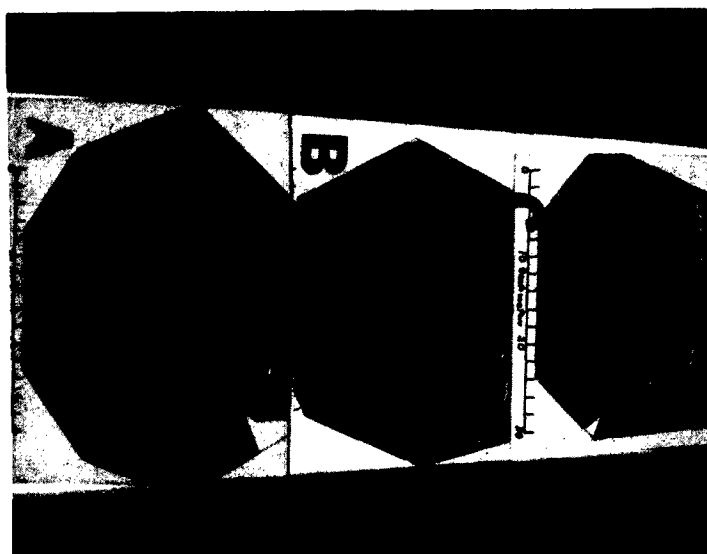
Figure 9. ULTRASONIC SCANS AT 6 SELECTED POSITIONS
ON 3 SUBJECTS

II LOWER TRUNK

TABLE IV

COMPARISON OF SUBJECTS USING SELECTED TRUNK SECTIONS

		Area Measurements				
Subject	Section	Total	Skin & Fat	Bone	Muscle	Body Cavity
A	1	165.5	32.6	17.5	100.7	14.8
	2	196.3	43.5	16.6	60.0	76.2
	3	220.3	29.5	15.3	53.8	121.7
	4	224.4	48.2	8.7	61.5	106.0
	5	222.0	50.2	14.6	97.2	60.0
	6	247.4	56.8	34.1	129.1	27.4
	Total	1276.0	260.8	106.8	502.3	406.1
	%	100.0	20.4	8.4	39.4	31.8
B	1	124.3	26.6	16.9	70.5	10.3
	2	168.9	23.1	14.2	75.9	55.7
	3	149.4	17.2	12.0	38.0	82.2
	4	150.2	18.8	5.9	38.9	86.6
	5	136.2	23.1	10.8	75.0	27.3
	6	173.2	27.1	28.0	97.3	20.8
	Total	902.2	135.9	87.8	395.6	282.9
	%	100.0	15.1	9.7	43.8	31.4
C	1	99.0	8.6	13.1	66.8	10.5
	2	110.7	11.5	14.5	45.9	38.8
	3	119.8	8.3	12.3	26.6	72.6
	4	99.5	11.5	4.9	29.7	53.4
	5	75.2	7.8	8.8	37.6	22.0
	6	121.2	10.0	19.1	78.6	13.5
	Total	625.4	56.7	72.7	285.2	210.8
	%	100.0	9.1	11.6	45.6	33.7
Cadaver	1	139.1	23.4	29.9	62.3	23.5
	2	159.8	13.6	12.5	45.6	88.1
	3	161.9	17.5	9.0	31.4	104.0
	4	146.0	23.5	7.8	49.1	
	5	153.2	35.6	25.4	49.5	42.7
	6	154.8	38.1	32.2	65.0	19.5
	Total	914.8	151.7	116.8	302.9	343.4
	%		16.6	12.8	33.1	37.5

TABLE V

COMPARISON OF SUBJECTS THIGHS AND TRUNKS

I. Thighs (From Appendix tables XII, XVI, and XVIII)

Subject	Number of Sections	Total Volume cc	Percent		
			Fat & Skin	Bone	Muscle
A	33	2080.6	24.4	5.8	69.7
B	34	1730.6	17.8	9.0	73.3
C	35	1227.5	15.9	9.0	75.1

II. Trunk (From table IV)

Subject	Total Volume cc	Fat & Skin	Percent		Body Cavity
			Bone	Muscle	
A	1276.0	20.4	8.4	39.4	31.8
B	902.2	15.1	9.7	43.8	31.4
C	625.4	9.1	11.6	45.6	33.7

tissue components are similar to those which would be expected, although we might have suspected that subject C would have had a lower percentage of fat and skin. In the lower half of table V the tissue components for the trunk of the three human subjects are shown for comparison with similar information from the upper legs.

We felt that it would be interesting to make a prediction or an estimation of total body composition of the three subjects based on the ratio of the percentage of each tissue component in subject B's trunk as compared to the total body. By comparing the estimated composition from the summation of six sections on B, as compared to the actual values of subject B (table III), we obtained a ratio for skin and fat of 1.17, bone 1.00, muscle 1.20, and body cavity 0.63. These prediction factors were used to adjust the comparable values of subjects A and C from the trunk measurement to predict total body composition. You will notice from table VI that with this technique we accounted for approximately 99.6% of the composition of subject A and 98.1% of subject C.

The estimation of body fat by the ultrasonic technique as recorded in table VII was compared with the estimates from densitometry. There appears to be considerable variation in absolute values between the methods used, although the relationship between the various techniques appear to be very high.

Differences in the values for body fat by these methods indicate that they are not measuring the same body components. (Allen et al, 1955) discussed the relationship between external and internal adiposity.

The body fat values reported by the ultrasound method are for the skin and subcutaneous fat, and the densitometric method estimates total body fat. The body fat value which appears out of line is the 5.4% value obtained by the densitometric method on subject C.

SECTION IV

CONCLUSION AND RECOMMENDATIONS

CONCLUSIONS

The first phase of this study involved the use of ultrasonic equipment and techniques to scan by surface contact a live anesthetized hog throughout 360 degrees, in so far as possible, at each of 13 positions. This was accomplished with satisfactory results but it was evident that an easier, faster, more accurate and repeatable method would be needed. Several transducer guides of different

TABLE VI

COMPARISON OF ESTIMATED TOTAL BODY COMPOSITION OF THREE SUBJECTS

Subject	Skin & Fat	Bone	Muscle	Body Cavity	Total
A	23.9	8.4	47.3	20.0	99.6
B	17.7	9.7	52.2	20.3	99.9
C	10.6	11.6	54.7	21.2	98.1
Prediction Factor (B)	1.17	1.00	1.20	0.63	-

The ratio of the percent of each component of subject B in body trunk (table IV) to total body (table III) was used as the prediction factor for the estimation of total body composition of subjects A & C.

TABLE VII

BODY FAT ESTIMATED BY ULTRASOUND AND DENSITOMETRY

Subject	Age Years	Height cm	Weight kg	Ultrasound	Densitometry
A	24	176.1	109.3	23.9	31.3
B	29	182.1	83.2	17.7	16.0
C	30	161.5	52.5	10.6	5.4

shapes were used but it was difficult to fit the ultrasonic records that would show full detail of a complete cross section.

Several techniques of scanning were evaluated during Trial 1 of the second phase. This involved ultrasonic scanning of a ham from a recently slaughtered hog. Surface contact scanning, linear immersion scanning and curvilinear immersion scanning techniques were compared. The latter technique proved to be the optimum method and was used subsequently in various forms. The results from the 3 ham trials indicated that this technique could be used to scan a specimen at 1 cm intervals. The ultrasonic maps produced by this method resulted in values similar to those obtained by dissection.

One human subject was scanned throughout 360 degrees at one-centimeter intervals from forehead to ankle with ultrasound. The trunk and right upper leg of two other subjects were scanned at the same intervals.

Photographs of ultrasonic scans obtained by the immersion scanning technique were assembled and interpreted. The area of fat and skin, muscle, bone, and body cavity were determined by planimeter for each section. The sum of these parts added up to approximately the same weight as the body weight of subject B. The data from selected areas of subjects A and C appeared to be in line with the values expected for their respective body types.

A practical method for scanning all parts of the human body was developed. This method was comfortable for the subjects, although it would be desirable to speed up the rate of the scanning process to make it practical to evaluate large numbers of subjects. It was demonstrated in this study that it is feasible and possible to use current ultrasonic equipment to estimate the volume of fat, muscle, and bone tissue of the living human body.

Densitometric measurements, and anthropometric measurements were also made on each human subject.

The data determined by the ultrasound technique developed in this study appear to be realistic. The steady improvement and resolution of the ultrasonic scan prints with successive trials was gratifying. However it demonstrates that further expansion of the type of investigations carried out in this feasibility trial should be carried out.

RECOMMENDATIONS

The developments and refinements in the scanning technique used in this feasibility study have resulted in great improvements to the

method we started with. The results appear quite realistic and within the range which might be expected. It would appear that a continuation of these investigations is justified. There are several different lines of research that should be pursued in my estimation.

Animal investigations

There are a number of techniques that need to be further refined and methods validated by making observations on live animals, such as swine and sheep, which can be killed for immediate viewing of the section scanned.

Velocity studies of sound at the frequencies used need to be carried out on individual tissues and combinations in animals of varying degrees of fatness. This should be done to establish the true velocity and normal deviations within a tissue, adipose vs. muscle, and to see if there is an interaction when we have large amounts of fat within muscle, i.e., marbling. Velocity studies should also be carried out on the various couplants that are used. A more careful investigation of the effect of temperature and concentration of salt in the solution used in immersion scanning should be carried out.

Additional studies of tissue components in segments and bodies of animals measured by ultrasound compared with other estimates of body composition are needed. Swine and man have many things in common but there are characteristics of sheep that would be much better to evaluate in a comparison with ectomorphic body types. Sheep could be used to study the growth of body components to a very fat condition and a period of weight reduction or starvation trials more effectively than swine.

It would be very desirable to locate a few particular sites for measuring tissue components that prove to be the best indices of total body composition.

Human investigations

Additional studies should be carried out with large numbers of humans of diverse body types to establish norms and variations by the ultrasonic scanning method as compared with other methods. It would seem logical to carry out many of the animal investigations first in order to have the most reliable and standarized method for use on humans.

Detailed evaluation of mass segments of particular interest on the human body should be carried out after improved resolution and sensitivity.

APPENDIX

TABLE VIII

ANTHROPOMETRIC MEASUREMENTS

	Subject		
	A	B	C
Age, years	24	29	30
Weight, kg	109.3	83.2	52.5
Stature	176.1	182.1	161.5
Biocromial Breadth	44.2	42.5	35.2
Chest Breadth	38.0	40.4	27.8
Waist Breadth	38.5	31.2	25.1
Hip Breadth	40.0	36.2	32.0
Chest Depth	31.6	25.2	20.4
Waist Depth	31.1	21.1	16.6
Hip Depth	21.6	24.3	19.7
Neck Circumference	42.0	39.3	34.3
Chest Circumference	117.4	109.5	81.7
Waist Circumference	112.4	85.2	68.1
Hip Circumference	111.4	102.2	84.7
Upper Thigh Circumference	66.6	61.6	46.7
Calf Circumference R	43.1	38.0	33.1
Biceps Circumference(Extended)	40.1	32.9	26.3
Biceps Circumference (Flexed)	42.0	34.7	27.4
Forearm Circumference(Extended)	33.1	28.6	26.0
Biepicondylar Humeral Breadth			
R.	7.0	7.2	6.8
L.	7.4	7.3	6.7
Biepicondylar Femeral Breadth			
R.	9.4	10.1	9.4
L.	10.1	10.1	9.4
SKINFOLDS			
Triceps	135	77	38
Biceps	106	33	27
Juxta Nipple	112	94	51
Mid-axillary Line(Umbilicus)	158	101	46
Supra Patella	74	65	42
Calf Med.	136	73	40
Post.	106	-	43

TABLE IX

AREA MEASUREMENTS FROM ULTRASONIC MAPS

Subject   - B

Body Region - Head and Neck scanned at 1 cm intervals

Location   - Head - Section No. 1 is located at the upper portion
                     of the frontal process of the maxilla
              Neck - Section No. 1 is located at the fourth
                     cervical vertebra

	Section No.	Total	Fat & Skin	Bone	Cavity	Lean
Head	1	61.1	11.5	44.1*		5.5
	2	63.3	12.4	46.9*		4.0
	3	59.9	10.8	44.1*		5.0
	4	59.2	8.6	40.0*		10.6
	5	63.3	6.5	41.7*		15.1
	6	68.0	7.5	47.2*		13.3
	7	54.4	7.2	20.3*	7.5	26.9
	8	61.8	10.2	11.0*	6.5	40.6
	9	58.1	10.6	15.4*	7.8	32.1
	10	64.7	10.5	19.2*	9.8	35.0
	11	42.9	8.2	8.2*	1.0	26.5
	Total	656.7	104.0	338.1*		214.6
	%		15.8%	51.5%		32.7%
Neck	1	43.3	11.0	5.1	1.6	25.6
	2	41.9	7.0	4.1	2.0	28.8
	3	44.1	7.4	3.4	2.8	30.5
	Total	129.3	25.4	12.6	6.4	84.9
	%		19.6%	9.7%	4.9%	65.7%

*Bone and Body Cavity

TABLE X

AREA MEASUREMENTS FROM ULTRASONIC MAPS

Subject   - B

Body Region   - Upper Trunk scanned at 1 cm intervals

Location   - Section No. 1 is located at the lower portion of the fifth
                cervical vertebra

Section No.	Total	Fat & Skin	Bone	Muscle	Body Cavity
1	67.3	22.4	3.0	36.9	5.0
2	104.6	46.6	4.7	50.3	3.0
3	108.6	50.5	7.0	47.7	3.4
4	118.9	54.3	7.5	52.6	4.5
5	126.5	34.9	22.6	62.0	7.0
6	141.0	29.3	21.1	80.3	10.3
7	144.9	36.9	19.5	81.2	7.8
8	159.6	23.5	12.5	106.2	17.4
9	172.2	28.4	8.7	110.1	25.0
10	170.8	31.0	11.0	100.3	28.5
11	177.7	21.7	13.3	102.0	40.7
12	172.6	35.2	12.1	77.2	48.1
13	169.7	18.1	13.1	93.8	44.7
14	160.9	21.4	13.5	82.6	43.4
15	171.0	21.8	13.4	72.8	63.0
16	168.9	23.1	14.2	75.9	55.7
17	167.6	24.0	14.4	61.0	68.2
18	172.9	21.5	11.6	51.3	88.5
19	161.0	18.6	12.0	49.6	80.8
20	168.8	21.8	11.5	47.6	87.9
21	165.0	20.4	11.6	48.6	84.4
22	161.9	18.9	11.4	39.2	92.4
23	160.8	17.1	11.1	38.9	93.7
24	162.1	16.7	13.6	39.4	92.4
25	152.5	17.8	11.6	38.5	84.6
26	149.4	17.2	12.0	38.0	82.2
27	147.5	16.6	11.9	38.0	81.0
28	147.7	15.7	15.0	33.2	83.8
29	150.3	16.5	12.0	40.8	81.0
30	142.1	13.0	8.5	39.8	80.8
31	151.6	16.4	7.0	43.4	84.8
32	142.7	12.4	6.7	42.0	81.6
33	151.6	18.1	8.8	42.8	81.9
34	149.1	19.8	5.2	41.3	82.8
35	153.2	18.0	6.4	38.0	90.8
36	150.2	18.9	5.9	38.9	86.6
Total	5443.2	857.9	405.4	2082.2	2097.7
%		15.8%	7.4%	38.3%	38.5%

TABLE XI

AREA MEASUREMENTS FROM ULTRASONIC MAPS

Subject   - B

Body Region - Lower Trunk scanned at 1 cm intervals

Location   - Section No. 37 is located at the upper portion of the third
               lumbar vertebra

Section No.	Total	Fat & Skin	Bone	Muscle	Body Cavity
37	157.6	20.6	5.4	41.6	90.0
38	150.4	13.6	7.0	42.9	86.9
39	151.4	19.4	5.0	47.5	79.5
40	146.1	21.7	5.2	55.3	63.9
41	145.6	23.9	5.8	43.8	72.1
42	139.0	23.1	4.9	47.5	63.5
43	139.8	24.8	5.4	40.8	68.8
44	134.3	22.9	5.8	50.2	55.4
45	130.0	22.9	3.5	39.5	64.1
46	130.5	29.5	8.0	39.0	54.0
47	124.0	22.1	10.9	45.5	45.5
48	128.0	23.3	8.9	62.8	33.0
49	136.0	23.1	10.6	75.0	27.3
50	137.3	24.4	12.5	72.6	27.8
51	129.8	21.8	16.4	63.2	28.4
52	154.9	25.8	19.5	77.3	32.3
53	153.6	26.8	26.4	72.0	28.4
54	182.6	26.3	17.5	94.2	44.6
55	168.4	26.2	15.9	84.0	42.3
56	162.5	24.8	15.1	82.6	40.0
57	163.1	42.5	16.5	86.6	35.5
58	181.1	25.6	22.6	103.5	29.4
59	174.8	24.7	17.7	93.5	38.9
60	156.8	23.3	15.4	94.7	23.4
61	165.5	23.0	21.1	87.0	34.4
62	162.3	22.1	21.4	83.8	35.0
63	158.6	28.6	27.7	85.1	17.2
64	160.0	22.5	32.7	84.3	20.5
65	173.2	27.1	28.0	97.3	20.8
66	167.8	34.7	22.6	97.5	13.0
67	171.8	41.5	17.2	104.1	9.0
68	176.0	40.8	15.5	109.5	10.2
69	192.0	43.3	12.5	130.4	5.8
70	165.6	36.1	5.3	124.2	-
Total	5270.4	884.8	485.9	2558.8	1340.9
%		16.8%	9.2%	48.6%	25.4%

TABLE XII

AREA MEASUREMENTS FROM ULTRASONIC MAPS

Subject   - B

Body Region - Upper Leg scanned at 1 cm intervals

Location   - Section No.1 is located through the femur just below the
              lesser trochanters and the ischial tuberosities

Section No.	Total	Fat & Skin	Bone	Muscle
1	74.3	8.8	2.0	63.5
2	72.1	9.3	2.0	60.8
3	76.8	8.3	1.7	66.8
4	78.9	13.0	2.3	63.6
5	79.6	12.4	1.8	65.4
6	79.0	9.6	1.9	67.5
7	60.8	8.0	1.9	50.9
8	66.3	9.8	2.0	54.5
9	66.2	6.0	1.6	58.6
10	65.6	8.0	1.8	55.8
11	61.2	7.8	2.1	51.3
12	61.1	7.7	2.2	51.2
13	59.6	8.0	2.2	49.4
14	58.5	7.4	2.8	48.3
15	60.4	7.5	2.6	50.3
16	50.6	5.6	2.4	42.6
17	48.9	7.9	2.3	39.6
18	43.5	7.1	2.3	34.1
19	46.2	7.0	2.9	36.3
20	46.3	6.4	3.3	36.0
21	42.7	6.1	3.5	33.1
22	41.0	6.1	3.4	31.5
23	36.8	5.9	3.6	27.3
24	41.6	6.5	5.7	29.4
25	34.8	5.4	4.6	24.8
26	36.5	5.5	6.8	24.2
27	33.8	10.9	5.9	17.0
28	31.8	18.1	4.1	9.6
29	30.9	19.0	7.5	4.4
30	30.3	14.9	11.2	4.2
31	31.0	12.9	13.7	4.4
32	28.0	11.1	13.5	3.4
33	29.0	10.7	14.7	3.6
34	26.5	9.7	12.8	4.0
Total	1730.6	307.5	155.7	1268.0
%		17.8%	9.0%	73.3%

TABLE XIII

AREA MEASUREMENTS FROM ULTRASONIC MAPS

Subject   -B

Body Region-Lower Leg scanned at 1 cm intervals

Location   -Section No. 1 is located at the upper end of the tibia

Section No.	Total	Fat & Skin	Bone	Muscle
1	30.2	12.0	15.3	2.9
2	29.0	12.3	11.5	5.2
3	30.5	12.2	12.6	5.7
4	31.3	11.0	12.0	8.3
5	26.6	8.4	8.5	9.7
6	29.8	6.6	7.1	16.1
7	29.5	6.4	5.4	17.7
8	29.4	6.1	4.6	18.7
9	29.9	5.8	3.2	20.9
10	29.0	4.4	3.3	21.3
11	28.1	4.5	3.0	20.6
12	29.0	4.5	2.8	21.7
13	28.1	5.4	2.4	20.3
14	29.6	5.1	2.8	21.7
15	28.8	4.8	2.3	21.7
16	29.6	4.3	2.5	22.8
17	29.8	4.0	2.8	23.0
18	28.2	5.3	2.4	20.5
19	25.1	4.1	2.3	18.7
20	24.3	4.6	2.3	17.4
21	21.8	3.7	2.6	15.5
22	21.8	3.8	1.9	16.1
23	21.1	4.7	2.4	14.0
24	18.9	3.9	2.4	12.6
25	18.4	3.6	2.6	12.2
26	15.1	3.3	1.8	10.0
27	15.2	3.2	2.4	9.6
28	12.8	2.8	2.2	7.8
29	12.6	2.6	2.0	8.0
30	13.7	3.4	2.6	7.7
31	14.2	3.1	1.8	9.3
32	12.2	2.4	2.4	7.4
33	13.0	3.2	3.0	6.8
34	13.6	4.8	3.5	5.3
35	11.4	5.8	3.2	2.4
36	14.5	5.7	5.9	2.9
37	16.4	8.4	6.0	2.0
38	14.9	8.6	6.3	-
39	14.5	6.8	7.7	-
40	15.5	8.8	6.7	-
41	18.0	10.0	8.0	-
42	20.8	9.0	11.8	-
Total	926.2	243.2	198.3	484.5
%		26.3%	21.4%	52.3%

TABLE XIV

AREA MEASUREMENTS FROM ULTRASONIC MAPS

Subject   - B

Body Region - Upper Arm scanned at 1 cm intervals

Location   - Section No. 1 is located just below the head of the humerus

Section No.	Total	Fat & Skin	Bone	Muscle
1	33.5	4.4	2.4	26.7
2	35.2	3.8	3.1	28.3
3	32.5	2.4	2.7	27.4
4	27.3	3.4	2.4	21.5
5	27.6	3.4	2.2	22.0
6	26.3	3.0	2.1	21.2
7	26.2	3.5	2.1	20.6
8	24.0	3.4	1.4	19.2
9	23.6	3.2	1.5	18.9
10	22.1	3.5	1.0	17.6
11	22.1	3.3	1.4	17.4
12	21.0	3.6	1.0	16.4
13	20.0	2.8	1.0	16.2
14	19.5	3.1	1.0	15.4
15	19.0	3.3	1.2	14.5
16	17.7	3.0	1.3	13.4
17	15.2	2.6	1.1	11.5
18	15.3	2.9	1.1	11.3
19	16.4	3.0	2.3	11.1
20	17.0	2.5	4.1	10.4
21	16.6	2.9	6.1	7.6
22	18.2	2.9	3.6	11.7
Total	496.3	69.9	46.1	380.3
%		14.1%	9.3%	76.6%

TABLE XV

AREA MEASUREMENTS FROM ULTRASONIC MAPS

Subject   - B

Body Region - Lower Arm scanned at 1 cm intervals

Location   - Section No. 1 is located at the humerus-radius junction

Section No.	Total	Fat & Skin	Bone	Muscle
1	17.4	3.3	5.4	8.7
2	19.6	4.4	4.7	10.5
3	18.8	4.0	2.4	12.4
4	18.0	4.2	1.8	12.0
5	18.7	4.0	1.5	13.2
6	20.2	4.0	2.0	14.2
7	18.7	3.6	2.0	13.1
8	19.5	4.3	2.0	13.2
9	18.7	3.7	1.7	13.3
10	20.8	3.7	1.5	15.6
11	18.4	3.1	1.5	13.8
12	20.0	3.6	1.6	14.8
13	19.8	4.1	1.7	14.0
14	17.4	3.1	1.8	12.5
15	18.1	3.7	1.7	12.7
16	15.1	2.8	1.9	10.4
17	13.6	2.7	1.5	9.4
18	15.7	3.2	1.7	10.8
19	14.9	3.0	1.8	10.1
20	11.5	3.9	1.5	6.1
21	10.0	2.2	1.6	6.2
22	7.9	2.7	1.3	3.9
23	8.4	2.4	1.6	4.4
24	6.6	2.6	1.6	2.4
25	7.3	2.5	3.5	1.3
26	7.0	4.2	1.8	1.0
27	7.2	4.2	2.0	1.0
Total	409.3	93.2	55.1	261.0
%		22.8%	13.5%	63.8%

TABLE XVI

AREA MEASUREMENTS FROM ULTRASONIC MAPS

Subject   - A

Body Region - Upper Leg scanned at 1 cm intervals

Location   - Section No. 1 is located through the femur just below
               the lesser trochanters and the ischial tuberosities

Section No.	Total	Fat & Skin	Bone	Muscle
1	86.8	19.7	2.4	64.7
2	85.7	21.3	1.8	62.6
3	85.2	20.4	1.8	63.0
4	85.0	19.4	2.6	63.0
5	80.1	18.5	2.0	59.6
6	79.3	19.6	2.0	57.7
7	77.2	16.3	1.6	59.3
8	80.4	18.3	1.5	60.6
9	79.5	17.5	1.6	60.4
10	76.7	17.8	1.7	57.2
11	76.0	17.4	1.8	56.8
12	75.9	16.1	1.8	58.0
13	76.4	17.8	1.7	56.9
14	74.4	16.9	2.2	55.3
15	73.4	13.9	1.9	57.6
16	70.7	13.8	1.8	55.1
17	71.2	15.2	2.1	53.9
18	64.2	13.9	1.8	48.5
19	62.0	13.1	1.9	47.0
20	55.4	12.6	1.6	41.2
21	46.6	12.4	2.1	32.1
22	53.6	12.4	2.1	39.1
23	50.9	11.1	2.0	36.9
24	48.1	10.5	2.4	35.2
25	44.9	11.0	2.2	31.7
26	45.0	9.8	2.8	32.4
27	40.4	10.8	2.6	27.0
28	43.7	12.3	4.8	26.6
29	38.9	14.1	4.9	19.0
30	37.5	14.7	10.8	12.0
31	40.1	15.9	16.3	7.9
32	38.4	15.0	16.4	7.0
33	38.8	18.6	14.3	5.9
Total	2080.6	508.1	121.3	1451.2
%		24.4%	5.8%	69.7%

TABLE XVII

AREA MEASUREMENTS FROM ULTRASONIC MAPS

Subject   - C

Body Region - Upper Leg scanned at 1 cm intervals

Location   - Section No. 1 is located through the femur just below
   the lesser trochanters and the ischial tuberosities

Section No.	Total	Fat & Skin	Bone	Muscle
1	48.9	5.2	1.7	42.0
2	46.7	4.6	1.3	40.8
3	44.7	4.4	1.2	39.1
4	44.4	4.8	1.7	37.9
5	45.1	5.1	1.3	38.7
6	45.7	5.7	1.4	38.6
7	51.4	5.7	2.3	43.4
8	42.1	5.8	1.8	34.5
9	45.1	5.3	1.8	38.0
10	42.9	5.3	1.8	35.8
11	45.0	7.9	1.8	36.2
12	41.0	5.5	2.2	33.3
13	42.7	5.5	2.7	34.5
14	38.9	4.2	2.0	32.7
15	37.9	4.6	1.9	31.4
16	37.0	4.2	2.0	30.8
17	33.4	4.3	1.5	27.6
18	37.0	4.5	2.1	30.4
19	34.7	4.5	2.1	28.1
20	34.5	3.5	2.7	28.3
21	30.1	3.5	2.5	24.1
22	29.7	4.3	2.4	23.0
23	29.0	4.6	2.4	22.0
24	28.6	4.3	2.5	21.8
25	24.8	4.2	1.7	18.9
26	25.7	4.3	2.9	18.5
27	24.3	4.2	3.4	16.7
28	23.3	4.2	3.0	16.1
29	25.1	5.4	3.9	15.8
30	23.1	4.9	3.5	14.7
31	24.6	7.0	7.0	10.6
32	24.4	8.9	7.3	8.2
33	26.8	10.9	12.8	2.1
34	25.0	11.1	10.1	3.8
35	23.9	13.5	8.3	2.1
Total	1227.5	195.0	111.0	921.5
%		15.9%	9.0%	75.1%

TABLE XVIII

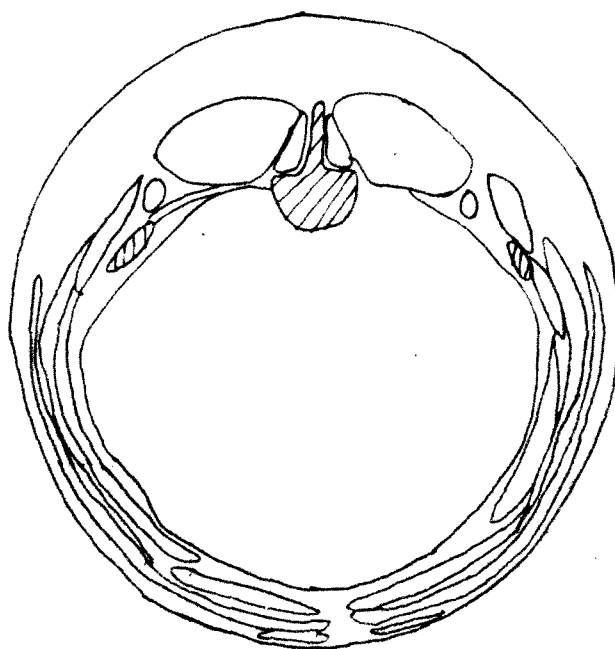## DENSITY MEASUREMENTS

Subject	Residual Air ml.	Density gm/cc	Specific Gravity	% Body Wt. as Fat (Rathbun-Pace Formula)
A	1246	1.0287	1.0356	31.33
B	1307	1.0496	1.0662	15.95
C	1147	1.0814	1.0882	5.43

Densitometric measurements were made on 12-15-67 by Professor Charlotte M. Young, Graduate School of Nutrition, Cornell University, Ithaca, N.Y.
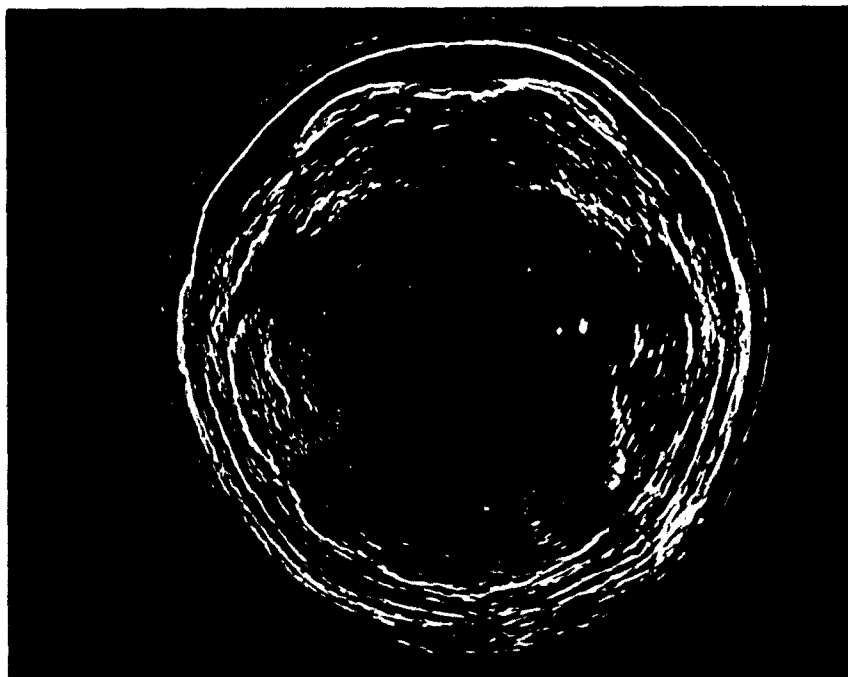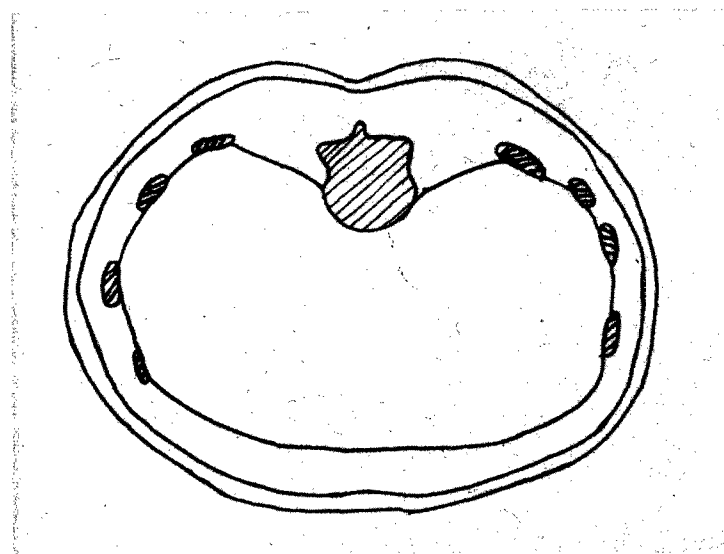
A. ULTRASONIC SCAN

B. LINE DRAWING

FIGURE 10. COMPARISON OF LINE DRAWING WITH ORIGINAL ULTRASONIC
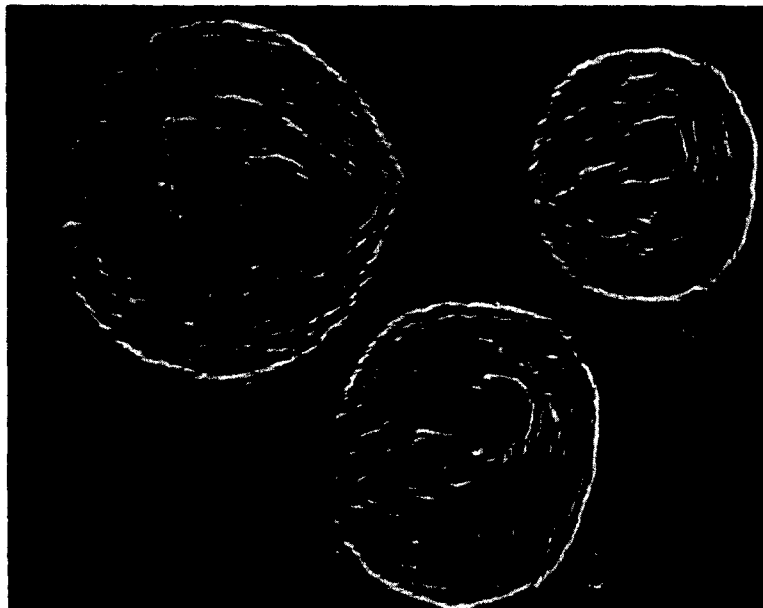SCAN OF HOG SECTION G. X4.
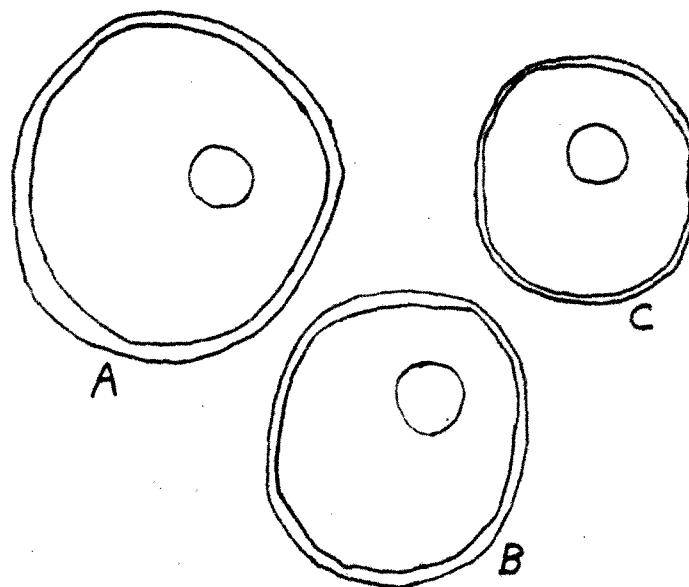
A. ULTRASONIC SCAN

B. LINE DRAWING

FIGURE 11. COMPARISON OF A LINE DRAWING WITH ORIGINAL ULTRASONIC
SCAN OF SUBJECT B UPPER TRUNK SECTION NO. 32. X4.

A. ULTRASONIC SCANS

B. LINE DRAWINGS

FIGURE 12. COMPARISON OF LINE DRAWINGS WITH ORIGINAL ULTRASONIC
SCANS OF UPPER LEG SECTION NO. 19 OF SUBJECTS A, B AND C. X4.

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13. ABSTRACT

The object of this study was to determine the feasibility of using ultrasonic techniques to determine the volume of fat, muscle, and bone tissue of the living body. Ultrasonic equipment, including a mechanical scanning and recording device was used to produce cross-sectional maps of a live anesthetized hog, three fresh hams, and three human subjects (endomorphic, mesomorphic, and ectomorphic). Thirteen 360° cross-sectional scans on the live hog demonstrated the feasibility of using the technique on live animals. Cross sections of the three hams demonstrated the accuracy of estimating the areas and volumes of the three tissue components from ultrasonic scans. The ultrasonic mapping of the human subjects demonstrated that the technique could be used on all parts of the human body and, in addition, provided an indication of the range of values of individuals of diverse body types.

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